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FROM STEAM TO IOT-SUPPORTED CROSS-BORDER LOGISTICS PLATFORMS: THE SOCIAL, ECONOMIC, AND LOGISTICAL IMPACTS OF THE INDUSTRIAL REVOLUTIONS

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Abstract: *This paper explores the economic, social, and logistical impacts of the four industrial revolutions, highlighting how each phase of industrialization transformed societies and economies. The analysis covers shifts in production methods, labor dynamics, and market structures that reshaped economic frameworks and influenced wealth distribution, job creation, and industry specialization. Social consequences, including urbanization, migration, and the development of new social classes, are examined to understand the broader implications on family dynamics, labor rights, and quality of life. The study also addresses the critical role of logistical advancements – from steam transportation to digital supply chains – in expanding markets and driving globalization.*

Keywords: *digitalization, industrial revolutions, logistics, society, supply chain, transportation,*

1. INTRODUCTION

Analyzing the economic, social, and logistical impacts of the industrial revolutions is crucial for understanding how these transformative periods reshaped societies. Each industrial revolution introduced innovations that dramatically altered economies, shifting production methods, labor dynamics, and market structures. By examining these economic changes, we gain insights into how wealth distribution, job creation, and industry specialization evolved, influencing modern economic frameworks. Social impacts were equally significant, as industrialization led to urbanization, changed family dynamics, and altered living conditions, often creating both opportunities and challenges for different social groups [1].

Understanding these social shifts, helps explain patterns of migration, the rise of new social classes, and shifts in labor rights, all of which continue to shape contemporary society. Logistical advancements played a key role, improving the transportation of goods and resources, which in turn supported expanding markets and global trade. Each revolution introduced new logistical solutions, from steam-powered trains to modern supply chain management, which fueled globalization and the efficient movement of products worldwide. Analyzing these logistical impacts reveals how innovations in transportation and communication enhanced connectivity and economic growth [2].

Moreover, studying these impacts allows us to prepare for future industrial changes, as past revolutions offer valuable lessons on both the benefits and risks of technological progress. By understanding how each industrial revolution influenced society, we can make more informed decisions in addressing current challenges, such as automation, sustainability, and equitable growth [3,4]. This analysis is also essential for policymakers who need to balance economic development with social well-being, ensuring that new technological shifts contribute positively to society.

In this paper, the author investigate how industrial revolutions influences economy, society and logistics.

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2. MATERIALS AND METHODS

Within the frame of this chapter, the main impacts of the industrial revolutions on various aspects are explored (economic impact, social and labor conditions, living and working issues, and logistical impacts). The economy is transformed through technological advancements and new manufacturing processes. Changes in social and labor conditions are examined, focusing on the shift from rural agricultural life to urban factory work. The challenges of living and working conditions in rapidly growing industrial cities, characterized by overcrowding and poor sanitation, are discussed. Finally, the revolutionized movement of goods and people due to innovations in logistics and transportation, such as the steam engine, is analyzed.

2.1. First Industrial Revolution

The First Industrial Revolution began in the late 18th century, around the 1760s, in Britain, and later spread to other parts of Europe and the United States. It was driven by innovations such as James Watt's steam engine, mechanized textiles, and advancements in iron production, which revolutionized manufacturing processes. This period, lasting until the early 19th century, saw the rise of factories, urbanization, and significant changes in labor systems, greatly transforming economies and social structures. The First Industrial Revolution has significant economic, social and logistical impacts as follows [5-9]. Fig. 1 summarizes the impact of inventions within the frame of the 1st Industrial Revolution.

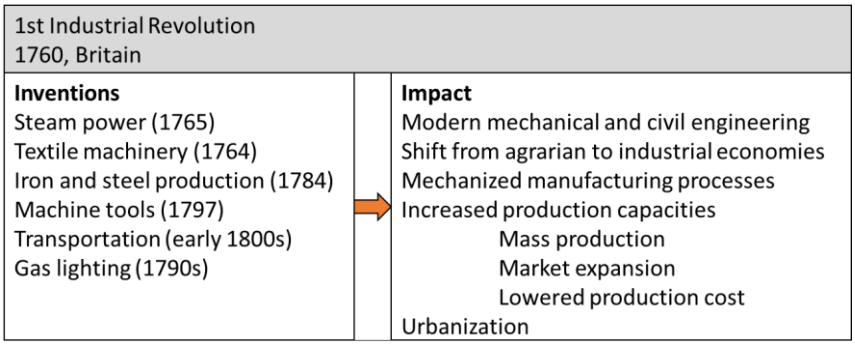

Figure 1. *Impact of the inventions within the frame of the 1st Industrial revolution*

Economic Impacts: The First Industrial revolution's economic impacts focus on increased production capacities, widening of mass production and expansion of markets (globalization), and urbanization. The introduction of machines and mechanized manufacturing processes, like the steam engine, significantly increased production capacity and lowered production costs. Industrial manufacturing became faster and cheaper than manual production. Mass production made goods more widely available, creating new markets, especially in the textile and iron industries. Increased production efficiency led to economic growth. Industrial centers, especially in England, attracted labor, leading to rapid urbanization as people moved to cities for factory jobs.

Social and Labor Conditions: The First Industrial revolution's social impacts focus on the transformation of the labor market, specialization and division of labor, and class divisions. With the rise of factories, labor shifted from agriculture and craft industries to industrial production. People migrated to cities in large numbers to find work in factories. The workforce became increasingly specialized, with individuals performing monotonous, repetitive tasks in factories. This created a new type of social hierarchy in industrial settings. The industrial revolution created a divide between the working class (industrial laborers) and the bourgeoisie (factory owners, entrepreneurs), leading to growing social tensions. Industrial workers received low wages, while factory owners accumulated great wealth.

Living and Working Issues: The First Industrial revolution lead to the following living and working issues: workplace conditions, women and child labor, and social reforms. Factory workers, especially in the early years, faced inhumane working conditions. Long hours, low wages, poor hygiene, and hazardous environments were common in factories. During the industrial revolution, more women and children worked in factories, often for extremely low wages and in horrible conditions. This led to new social issues, such as the rise of child labor. The poor living and working conditions, along with increasing social inequality, led to social reforms, including labor laws and workers' rights protection.

Logistical Impacts: The First Industrial revolution has significant impact on logistics including transportation and infrastructure development, global trade, and strong connection between cities. The development of steamships, steam locomotives, and railways enabled faster and cheaper transportation of goods and raw materials. The expanding transportation network facilitated the growth of international trade. Industrial products could reach foreign markets more easily, and imported raw materials arrived faster at factories. Improved transportation infrastructure also strengthened connections between cities and industrial centers, contributing to the expansion of industrial production and economic growth.

2.2. Second Industrial Revolution

The Second Industrial Revolution began in the late 19th century, around the 1870s, primarily in the United States and Germany, though it also impacted Britain and other parts of Europe. This period was marked by rapid advancements in steel production, electrification, chemical manufacturing, and the expansion of railroads, which fueled large-scale industrial growth. Lasting until the early 20th century, the Second Industrial Revolution brought mass production techniques, such as the assembly line, and transformed economies, leading to increased urbanization and significant social changes [10-12]. The Second Industrial Revolution has significant economic, social and logistical impacts as follows. Fig. 2 summarizes the impact of inventions within the frame of the 2nd Industrial Revolution.

Economic Impacts: The Second Industrial revolution's economic impacts focus on technological advancements based on electricity, expansion of mass production, rise of multinational corporations, and the intensive growth of the financial market. Innovations such as electricity, the internal combustion engine, and the assembly line revolutionized production processes, significantly boosting manufacturing capabilities. These technologies enabled industries such as steel, chemicals, and electricity to grow rapidly. The use of assembly lines in manufacturing, most notably by Henry Ford in the automobile industry,

made mass production more efficient and products more affordable, leading to broader consumer markets and economic growth. With increased industrial output, companies grew larger and expanded across national borders, leading to the rise of multinational corporations and an interconnected global economy. The demand for capital to fund large-scale industries led to the growth of financial institutions, stock markets, and banking systems, which helped support further industrial development.

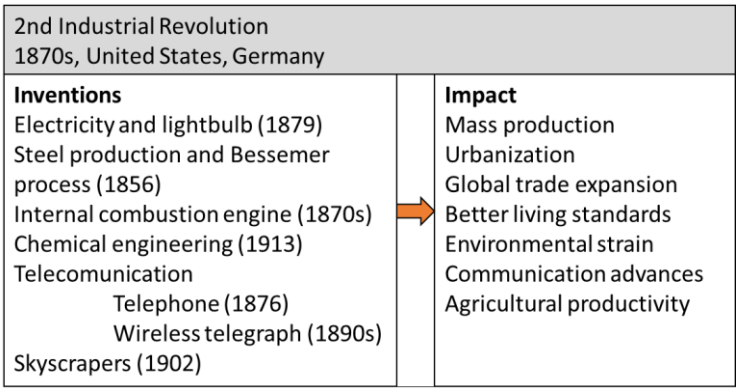

Figure 2. *Impact of the inventions within the frame of the 2nd Industrial revolution*

Social and Labor Conditions: The Second Industrial revolution's social impacts focus on urbanization, better labor conditions, and the rise of labor movements. The development of new industries in cities led to further migration from rural areas to urban centers. Cities grew rapidly, and the working class increasingly found employment in factories, leading to the creation of industrial urban societies. While labor reforms were introduced, such as limited working hours and safer factory conditions, factory work still remained difficult, especially for women and children. The working class continued to struggle for better pay and working conditions. The harsh working conditions led to the emergence of organized labor movements, strikes, and the creation of trade unions that fought for workers' rights, better wages, and safer conditions.

Living and Working Issues: The Second Industrial revolution lead to the following living and working issues: better standards of living, poor working conditions, child and women labor. The growth of industries led to the production of affordable consumer goods, such as clothing, tools, and even automobiles. The middle class, in particular, saw a rise in living standards with better housing, education, and access to goods and services. Despite some improvements in working conditions, many factory workers, especially in rapidly growing industrial centers, still lived in overcrowded and unsanitary conditions. Poor housing, lack of sanitation, and limited access to healthcare were widespread. Child labor remained a significant issue, as children were employed in factories and mines under harsh conditions. Women continued to work in low-wage factory jobs, often facing discrimination in wages and advancement.

Logistical Impacts: The Second Industrial revolution has significant impact on logistics including significant improvement in transportation processes, development in electricity and

communication, and appearance of global trade networks. The introduction of the internal combustion engine powered automobiles and trucks, while railroads expanded and became more efficient. These developments revolutionized the movement of goods and people, linking cities and countries more effectively. The widespread use of electricity in factories, homes, and transportation made industrial processes more efficient. Innovations like the telegraph, telephone, and radio improved communication across long distances, fostering greater interconnectedness and enabling faster business operations. Improved transportation and communication systems allowed for the expansion of global trade, with goods moving faster and more cheaply across borders. The establishment of international shipping networks and the growth of ports boosted global commerce.

2.3. Third Industrial Revolution

The Third Industrial Revolution, also known as the Digital Revolution, began in the late 20th century, around the 1970s, primarily in the United States, Japan, and Western Europe. It was characterized by the rise of electronics, computers, and information technology, which transformed manufacturing and introduced automation and digitalization to many industries. Spanning into the early 21st century, this revolution enabled globalization, reshaped communication and labor markets, and accelerated the shift toward a knowledge-based economy [13-16]. The Third Industrial Revolution has significant economic, social and logistical impacts as follows. Fig. 3 summarizes the impact of inventions within the frame of the 3rd Industrial Revolution.

Economic Impacts: The Third Industrial revolution's economic impacts focus on the appearance of information-based economies, robotics and automation, further globalization of the market, and creation of new industries. With the advent of computers, the internet, and digital technologies, economies became more reliant on information and services rather than traditional manufacturing. Industries like software, telecommunications, and IT services expanded rapidly. The rise of computer-controlled machines, robots, and automated production lines revolutionized manufacturing processes, increasing efficiency, reducing labor costs, and improving product quality. This shift led to the decline of traditional manual labor jobs in certain sectors. The growth of digital communication tools, like the internet, facilitated the globalization of trade and business. Companies could operate on a global scale, accessing new markets and customers from around the world, leading to increased international competition and collaboration. The digital revolution gave birth to entirely new industries, such as the tech industry (computers, software, electronics), biotechnology, and e-commerce, providing new job opportunities and driving economic innovation.

Social and Labor Conditions: The Third Industrial revolution's social impacts focus on further changes in work and employment, improved importance of education and training, labor displacement and inequalities. The rise of automation and digital technology altered the nature of work. While machines and robots replaced some jobs, new types of employment emerged in IT, services, and digital fields. Remote work and telecommuting became more prevalent due to advances in digital communication tools. As economies transitioned toward knowledge and service-based industries, there was a greater emphasis on education, particularly in fields like computer science, engineering, and data analytics. Workers needed specialized skills to keep up with technological advancements. While new technologies

created jobs in high-tech industries, automation and computerization also displaced many manual labor jobs, particularly in manufacturing. This shift led to growing inequality, with highly skilled workers benefiting the most, while low-skilled workers faced job losses and wage stagnation.

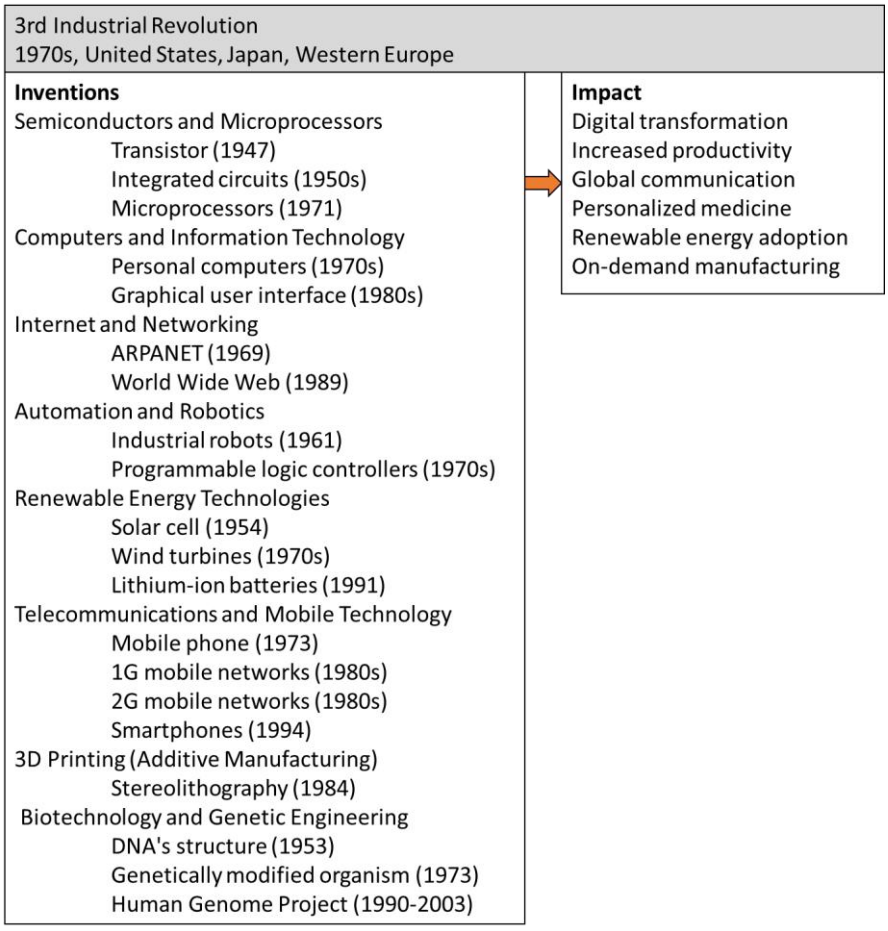

Figure 3. *Impact of the inventions within the frame of the 3rd Industrial revolution*

Living and Working Issues: The Third Industrial revolution lead to the following living and working issues: better standards of living, changes in workplace environment and working conditions, and growing digital divide in the society. The availability of new technologies, like personal computers, mobile phones, and the internet, transformed everyday life. People gained easier access to information, entertainment, and services, significantly improving their quality of life. The digital age enabled the growth of consumer electronics, which became integral to modern lifestyles. Workplaces became more digitized, with computers and automation systems transforming how people performed tasks. Offices were equipped with technology that facilitated faster communication and increased productivity. However, the shift to digital workplaces also created challenges, such as work-life balance issues due to

the constant connectivity provided by smartphones and email. While some people enjoyed the benefits of new technologies, others, particularly in developing countries or lower-income regions, struggled to access digital tools.

Logistical Impacts: The Third Industrial revolution has significant impact on utilization of advancements in communication and networking, e-commerce amd digital transactions, and supply chain automation and supply chain management. The development of the internet, mobile networks, and satellite communications revolutionized global communication. Businesses could easily share information across time zones and borders, fostering quicker decision-making and real-time collaboration. Online shopping and digital payment systems transformed commerce by providing consumers with easy access to a wide range of products and services. E-commerce giants like Amazon and Alibaba reshaped retail, and digital currencies began to emerge as new forms of money. Automation, robotics, and data analytics revolutionized supply chain management. Warehouses became more efficient with the use of automated systems, and companies used real-time data to optimize logistics and reduce costs. The ability to track goods globally, manage inventories efficiently, and automate distribution processes helped businesses achieve faster and more reliable operations.

2.4. Fourth Industrial Revolution

The Fourth Industrial Revolution, beginning in the early 21st century, is characterized by advancements in artificial intelligence, robotics, the Internet of Things (IoT), and biotechnology. Emerging in countries like the United States, Germany, China, and South Korea, this revolution merges physical, digital, and biological systems, creating highly connected and intelligent networks across industries. Its impact spans automation, smart factories, and new ways of working and living, as it transforms sectors from manufacturing to healthcare, with profound implications for economies and societies worldwide [17,18]. The Third Industrial Revolution has significant economic, social and logistical impacts as follows. Figure 4 summarizes the impact of inventions within the frame of the 4th Industrial Revolution.

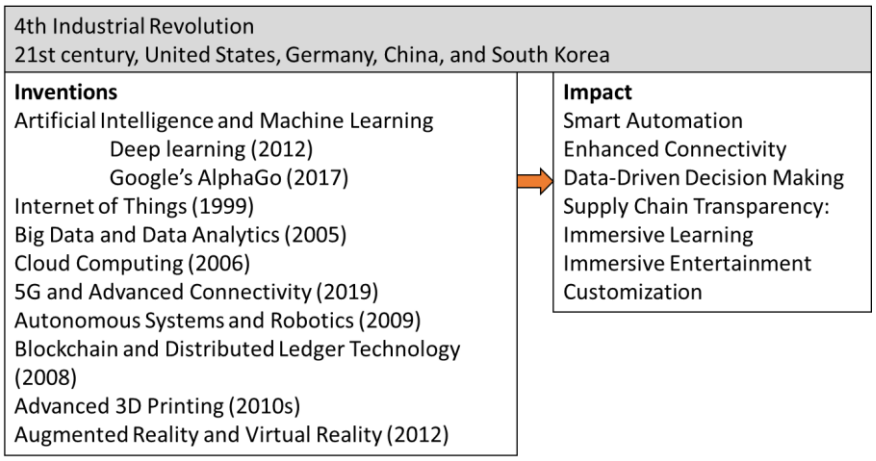

Figure 4. *Impact of the inventions within the frame of the 4th Industrial revolution*

Economic Impacts: The Fourth Industrial revolution's economic impacts focus on smart factories, digital economy expansion, transformation of labor markets, and shift to green and sustainable industries. The integration of AI, IoT, and robotics into production processes has led to the rise of smart factories, where machines are interconnected, and production is optimized in real-time using data. This has increased efficiency, reduced waste, and allowed for mass customization of products, fundamentally changing how businesses operate and compete. The digital economy, driven by advancements in AI, blockchain, and cloud computing, has become a key driver of economic growth. E-commerce, digital platforms, and online services have transformed industries, creating new business models and disrupting traditional ones. Gig economies, freelancing, and digital entrepreneurship have flourished as more people work remotely or as independent contractors. Automation and AI have the potential to significantly reduce the need for human labor in some industries, particularly those involving repetitive tasks. However, they also create opportunities for higher-skilled jobs in tech-driven fields like AI development, data science, and cybersecurity. The labor market is evolving toward a higher emphasis on technical skills, soft skills, and adaptability. Sustainability is a central focus of the Fourth Industrial Revolution, with innovations in clean energy, electric vehicles, and resource-efficient manufacturing processes. Green technologies and circular economy principles are gaining traction, as businesses and governments focus on reducing carbon footprints and addressing climate change.

Social and Labour Conditions: The Fourth Industrial revolution's social impacts focus on revolutionary changes in nature of work, remore work and collaboration, digital inclusion and equity issues, and human-machine interaction, collaboration and cooperation. The nature of work is changing rapidly with the introduction of AI, robotics, and automation. Many routine jobs are at risk of being replaced, but new types of employment in emerging technologies and industries are emerging. People are expected to adapt to these changes through continuous learning and upskilling. The COVID-19 pandemic accelerated the adoption of remote work, and it is expected to remain a dominant feature in the labor market. Digital collaboration tools and cloud platforms have enabled employees to work from anywhere, creating more flexible work arrangements and promoting work-life balance. While technological advancements have the potential to improve lives, there is also a growing concern over digital inclusion. Disparities in access to digital technologies, education, and connectivity could exacerbate social inequalities, both within and between countries. Ensuring equitable access to digital tools and opportunities will be crucial for addressing these challenges. The Fourth Industrial Revolution emphasizes the collaboration between humans and machines, particularly in industries like healthcare, education, and manufacturing. AI and automation are solutions that complement human work, rather than replace it, enabling people to focus on creative, strategic, and complex tasks.

Living and Working Issues: The Fourth Industrial revolution lead to the following living and working issues: better quality of life, smart cities, sustainable living, better work-life balance through automation, and data security and privacy concerns. Advances in healthcare, biotechnology, and personalized medicine are enhancing quality of life by offering better treatments, preventive measures, and longer life expectancy. Technologies like wearable health devices and telemedicine are empowering individuals to manage their health more effectively. The Fourth Industrial Revolution is enabling the development of smart cities, where technology is used to optimize infrastructure, transportation, energy use, and public

services. Urban areas are becoming more efficient, sustainable, and livable through innovations like autonomous vehicles, energy-efficient buildings, and smart grids. While automation has the potential to reduce working hours by taking over repetitive tasks, it also presents challenges in terms of balancing productivity with personal well-being. With more people working remotely and automating routine jobs, there is potential for greater flexibility and better work-life balance. As more aspects of daily life are digitized, the collection and use of personal data raise concerns about privacy, security, and surveillance. The increasing reliance on digital platforms and connected devices also opens up new risks related to cyberattacks, data breaches, and identity theft, necessitating stronger regulations and safeguards.

Logistical Impacts: The Fourth Industrial revolution has significant impact on intelligent supply chain solutions, development of novel decentralized solutions, autonomous transportation and delivery solutions, smart warehousing and inventory management solutions, and digital trade.

The intelligent supply chain solutions are generally based on real-time data tracking, predictive analytics, forecasting and resilience problems. One of the most significant impacts of the Fourth Industrial Revolution is the ability to track goods and shipments in real time. IoT devices embedded in products, vehicles, and warehouses allow companies to gather data on the location, condition, and status of goods at every stage of the supply chain. This provides companies with unprecedented visibility, enabling them to monitor inventory levels, anticipate delays, and make data-driven decisions in real time. By analyzing large amounts of data, AI and machine learning algorithms can predict demand more accurately, optimizing inventory management and reducing the need for excess stock. This allows businesses to operate with leaner inventories, reduce waste, and lower costs. Predictive analytics can also forecast potential disruptions or delays in the supply chain (such as weather conditions, geopolitical events, or factory shutdowns), allowing for proactive measures. Advanced technologies enable companies to respond more quickly and effectively to disruptions in the supply chain. Automated systems, real-time communication tools, and AI-powered decision-making help companies mitigate risks, reroute shipments, and adapt to unexpected events such as natural disasters or supply shortages. This increases the overall resilience of global supply chains, making them more flexible in responding to external pressures. The logistical impact of Industry 4.0 technologies can be demonstrated by a complex model of a case study, where the researchers studied the smart cyber-physical manufacturing, the real-time optimization of logistics resources in matrix production [19].

The novel decentralized solutions are supported by blockchain technology. Blockchain technology offers a decentralized, transparent, and immutable ledger that can be used to track the entire lifecycle of products as they move through the supply chain. Every transaction, from production to delivery, is recorded on the blockchain, which increases trust among participants by providing a tamper-proof record of goods' origin, status, and handling. Smart contracts, which are self-executing agreements with predefined conditions stored on a blockchain, enable more efficient and automated processes in logistics. These contracts automatically execute and enforce terms when specific conditions are met (e.g., payment processing, shipment verification), reducing the need for intermediaries and paperwork. This leads to faster transactions, fewer errors, and greater operational efficiency in the logistics and supply chain processes. Blockchain helps to eliminate fraud and counterfeiting by providing a transparent, verifiable, and unalterable record of transactions. In industries like

pharmaceuticals, food, and luxury goods, blockchain's ability to track every stage of a product's journey – from manufacturing to distribution – helps ensure authenticity and combat fraudulent practices.

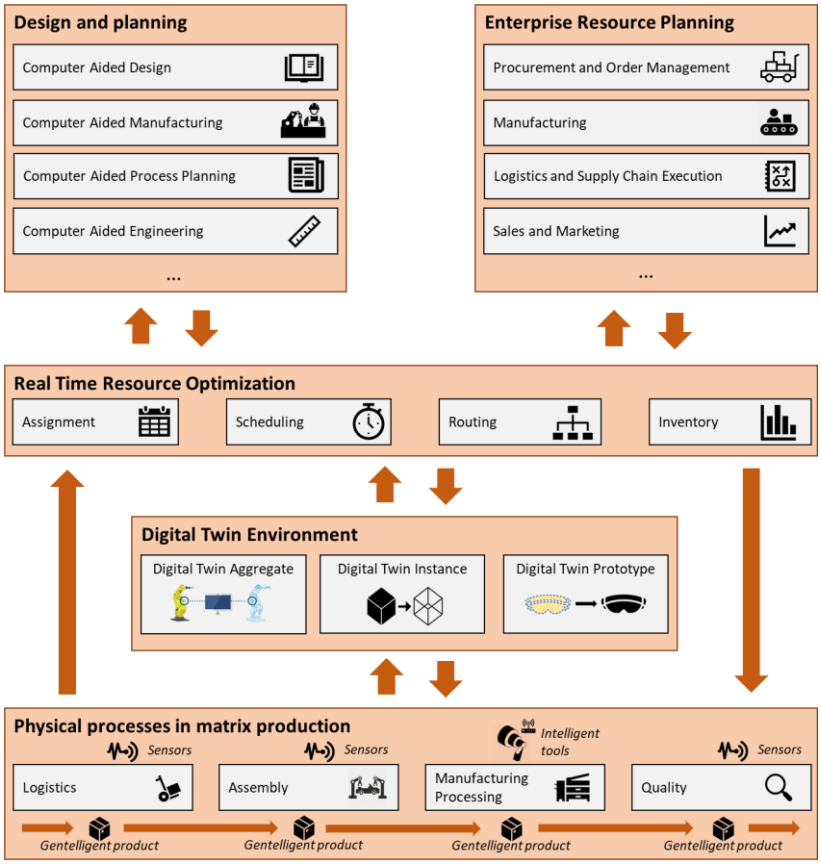

Figure 5. *Structure of real-time resource optimization in matrix production [19].*

The autonomous transportation and delivery solutions are based on autonomous vehicles, drones and other unmanned aerial vehicles, and process automation both in transportation and warehousing). The Fourth Industrial Revolution has made significant strides in the development of autonomous vehicles, including self-driving trucks and delivery vans. These vehicles are equipped with sensors, GPS, and AI algorithms that allow them to navigate roads and highways without human intervention. Autonomous trucks can operate 24/7, increasing efficiency and reducing transportation costs by eliminating the need for human drivers. They can also optimize routes in real time to avoid traffic and reduce fuel consumption. Drones are revolutionizing last-mile delivery in urban areas. With the ability to bypass traffic and reach customers directly, drones are capable of delivering goods faster and more efficiently. Retailers like Amazon are experimenting with drone delivery systems, and many logistics companies are looking into UAVs for delivering packages in less time and with lower costs, especially in remote or hard-to-reach areas. Robotics are increasingly being used in

warehouses for material handling, picking, packing, and sorting. Automated guided vehicles (AGVs) and robots work alongside human employees or replace human labor for repetitive tasks, enhancing productivity. These robots can work tirelessly, increasing the throughput of warehouses, while AI-powered systems help ensure the right items are picked and shipped efficiently.

Smart warehousing and inventory management solutions include IoT-enabled warehouse, high-performance sorting systems, and artificial intelligence in inventory forecasting. The use of IoT sensors and RFID (Radio Frequency Identification) technology in warehouses provides real-time tracking and management of inventory. Sensors monitor product movement, environmental conditions (such as temperature and humidity), and other relevant data to ensure that goods are stored correctly and can be easily located when needed. This reduces human error and improves the speed of order fulfillment. Automated sorting systems in warehouses use AI, robotics, and advanced conveyor systems to sort goods based on destination, size, or priority. These systems are faster and more accurate than manual sorting and reduce labor costs. They also enable warehouses to scale operations more efficiently without increasing labor requirements. AI algorithms can predict inventory needs based on historical data, customer behavior, and seasonal trends, which optimizes stock levels and reduces waste. These AI systems can make decisions about when to reorder products, how much to stock, and even where to store them within a warehouse based on demand forecasts. E-commerce platforms have revolutionized logistics by allowing businesses and consumers to engage in cross-border trade more easily. Digital platforms facilitate secure online transactions, global shipping options, and customer tracking, enabling the growth of international commerce. This interconnectedness allows businesses to expand their reach and access new global markets, while consumers benefit from a wider range of products. The rise of digital communication tools has made it easier for suppliers, manufacturers, and distributors to communicate and coordinate across borders. Supply chains can now operate on a global scale, with real-time data being shared instantaneously across different regions. This has led to a more synchronized, transparent, and efficient flow of goods and services across the world. Platforms that provide end-to-end logistics solutions for cross-border trade have become more common. These platforms offer integrated services, from customs clearance and documentation to transportation and delivery, simplifying the logistics process for businesses involved in international trade. This has made it easier and faster for businesses to ship goods across borders, further driving the globalization of supply chains.

3. RESULTS AND CONCLUSIONS

The First Industrial Revolution drastically changed the economy, society, and logistics by introducing new production and labor systems. Machines mechanized manufacturing, transforming life at every level while also creating new challenges and tensions. These changes laid the groundwork for the social and political reforms that followed in the coming decades.

The Second Industrial Revolution brought rapid technological and industrial advancements that led to mass production, economic growth, and the expansion of global trade. Some people saw improved living standards, but labor exploitation and social inequality remained significant issues. Innovations in transportation, communication, and manufacturing set the foundation for the modern industrialized world, driving important social changes like the rise of labor unions and the rapid growth of cities.

The Third Industrial Revolution introduced information technology, digital communication, and automation. It shifted economies toward services and technology, accelerating globalization and spawning entirely new industries. Socially, it changed the workforce, creating new job categories and increasing the demand for education and digital skills. While technology improved living standards and productivity, it also displaced workers and widened inequalities. Logistically, advances in communication, e-commerce, and supply chain management allowed businesses to operate more efficiently on a global scale, changing how goods and services were produced, distributed, and consumed.

The Fourth Industrial Revolution transforms industries, economies, and societies by integrating digital, physical, and biological systems. Technologies like AI, robotics, and IoT reshape labor markets, where automation may eliminate some jobs but create new ones in high-tech fields. This revolution offers both opportunities and challenges, such as the need for upskilling, addressing digital inclusion, and ensuring ethical technology use. Logistically, intelligent supply chains, autonomous transportation, and digital trade revolutionize how goods and services are produced and delivered globally. As this revolution continues, it will shape the future of work, life, and the global economy.

In the Institute of Logistics at the University of Miskolc, numerous research projects focus on various aspects of Industry 4.0, contributing to a deeper understanding and analysis of the impacts of industrial digitalization [20-24]. Researchers at the institute are working on developing smart manufacturing systems, applying robotics technologies, and implementing network-based solutions, all of which play a key role in transforming modern industry. They are also exploring the possibilities of data processing and artificial intelligence, which can optimize production processes. Another important area of research is improving sustainability and energy efficiency, addressing one of the main challenges of Industry 4.0 implementation. These studies aim not only to develop theoretical models but also to create practical, applicable solutions. Such research outcomes will significantly support the analysis of future industrial trends and technological innovations.

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